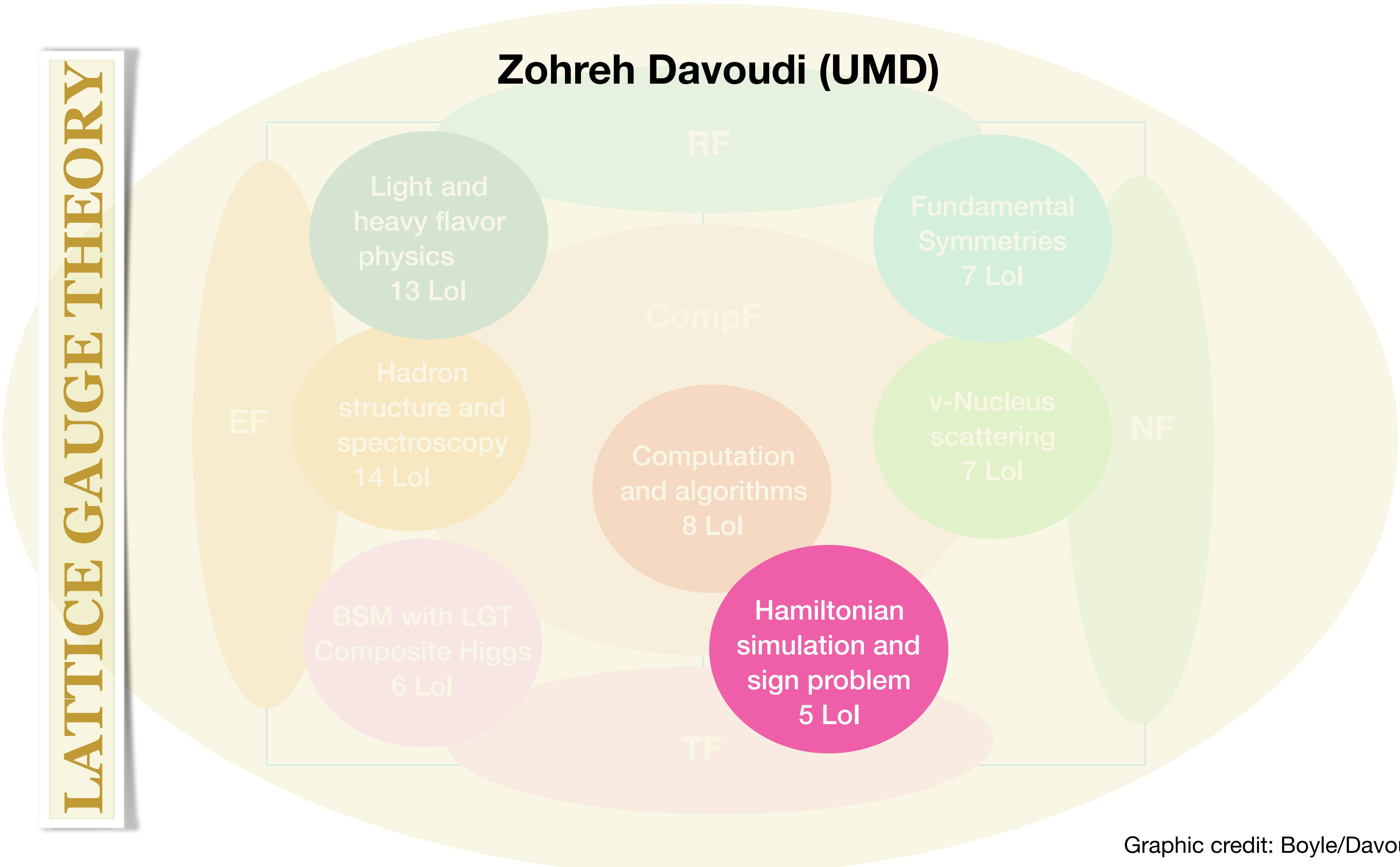
Hamiltonian simulation and other strategies to overcome the sign and signal-to-noise problem in LGT



Zohreh Davoudi (UMD)

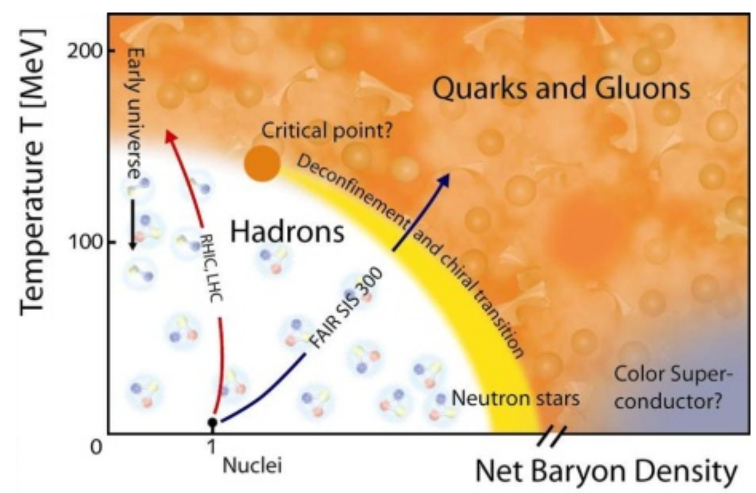
Graphic credit: Boyle/Davoudi

Snowmass CPM
Session 124: Lattice Gauge Theory for High Energy Physics
Oct 6, 2020

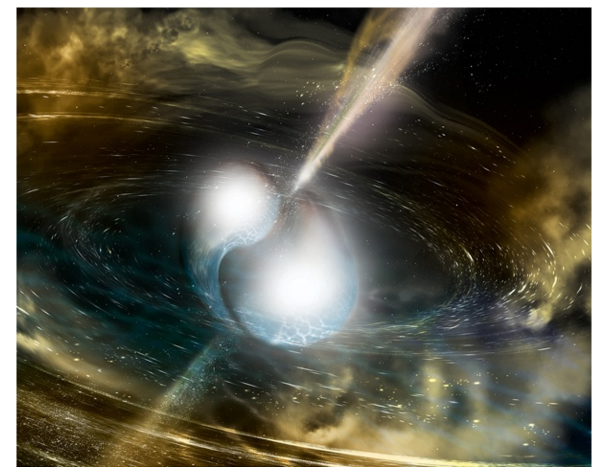
Sign problem has hindered important physics to be explored...

i) STUDIES OF DENSE MATTER AND PHASE DIAGRAM OF QCD.

$$\mathcal{L}_{\mathrm{QCD}} \to \mathcal{L}_{\mathrm{QCD}} - i\mu \sum_f \bar{q}_f \gamma^0 q_f$$



Source: The Facility for Antiproton and Ion Research (FAIR),GSI, Darmstadt, Germany.

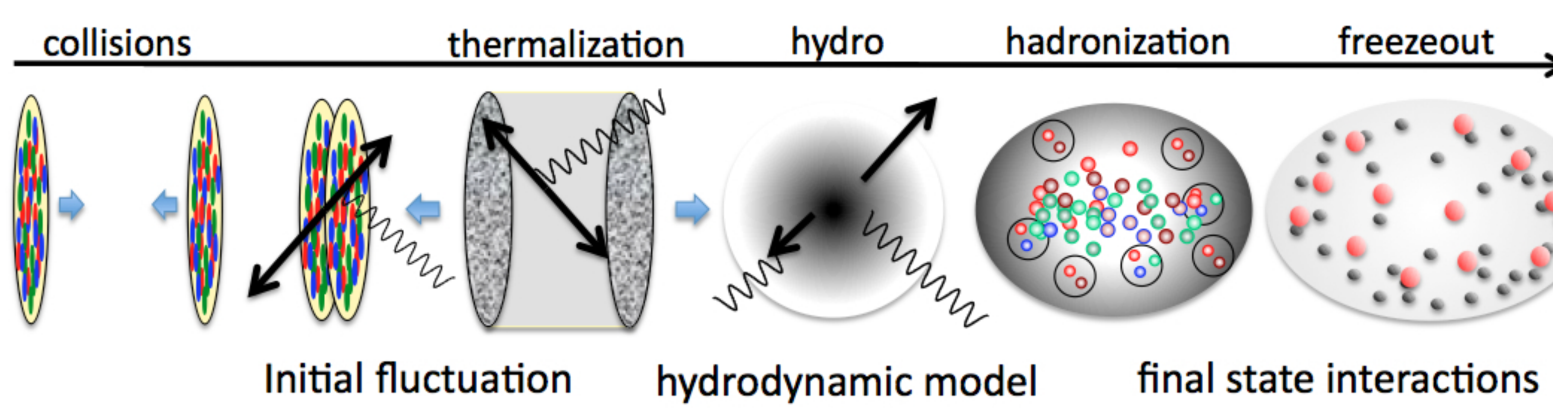


National Science Foundation/LIGO/Sonoma State University/A. Simonnet

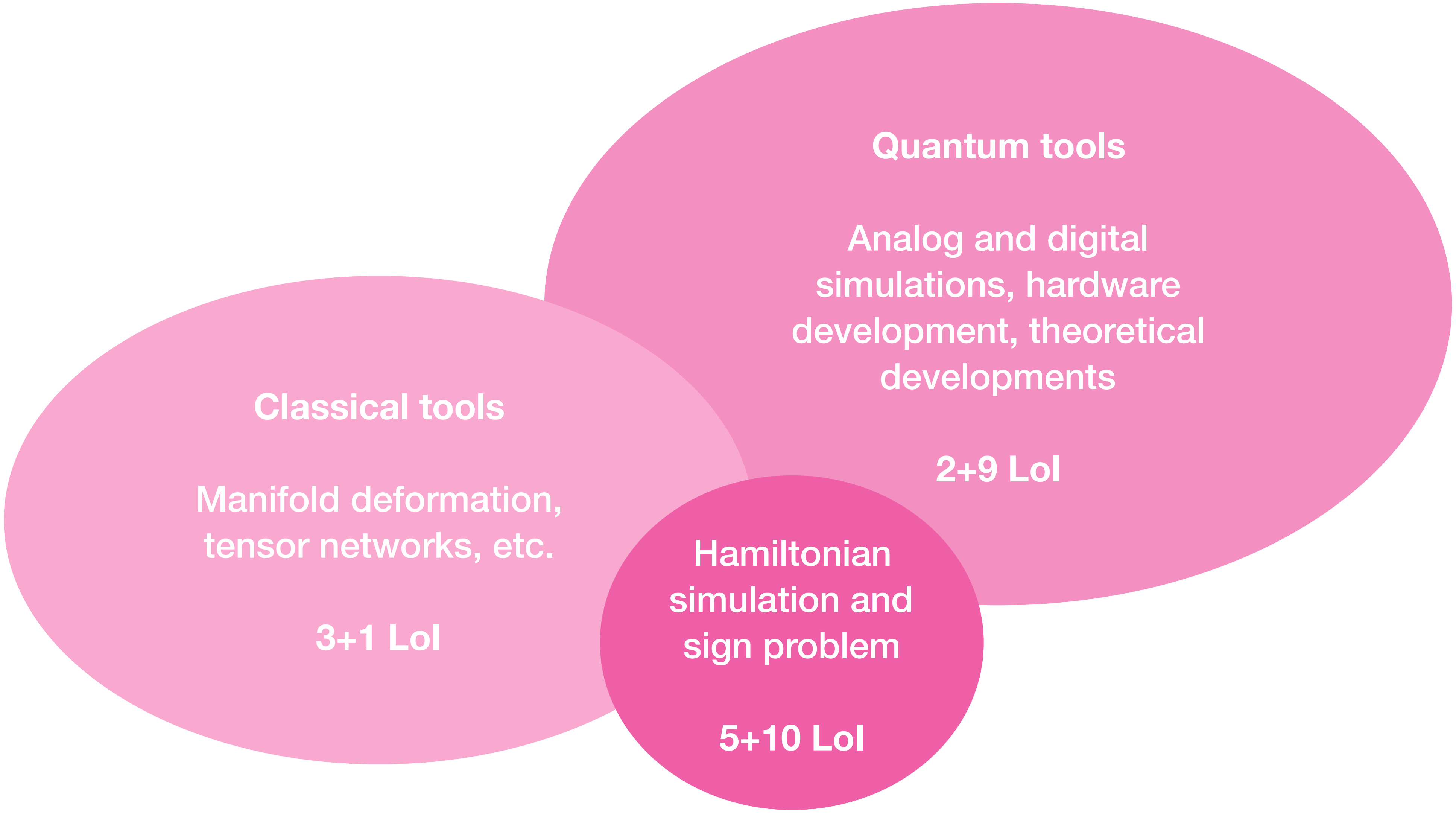
$$e^{iS(U,q,\bar{q})}$$

ii) REAL-TIME DYNAMICS OF MATTER, *e.g.*, IN HEAVY ION COLLISIONS OR AFTER BIG BANG.

$$e^{iH(U,q,\bar{q})t}$$



arXiv:1204.4795 [nucl-th]


Quantum tools
Analog and digital simulations, hardware development, theoretical developments
2+9 LoI
Classical tools
Manifold deformation, tensor networks, etc.
3+1 LoI
Hamiltonian simulation and sign problem
5+10 LoI

Approaches to mitigate or avoid sign problem based on classical computing

On The Need For Path Integral Contour Deformations To Tame the Sign Problem

Neill C. Warrington[1]

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fermionic model resembling QCD. Manifold deformations can be used to tame more than just sign problems, too. They can be used to tame signal-to-noise problems, which plague, for example, the calculation of the baryon mass from lattice QCD. This has been demonstrated recently in two low dimensional toy models [3].

extrapolated to zero. This alone makes this technique worth exploration and development. However, given as well the emergence of quantum computing as a technique to compute real-time observables, it is all the more important to have classically-obtained results with which to compare quantum calculations.

Approaches to mitigate or avoid sign problem based on classical computing

Tensor Networks in High Energy Physics

Y. Meurice[1], R. Somma[2], B. Şahinoğlu[2], G. Vidal[3].

University of Iowa[1], Los Alamos National Laboratory[2], X, the Moonshot Factory [3].

can directly benefit lattice QFT calculations by assisting Monte Carlo simulations. Overall, we envision a roadmap of simulating QFTs with/without gauge invariance and seeking new approaches for physical problems such as confinement, etc., by starting from 1+1D models towards 3+1D, e.g., Schwinger model $\rightarrow$ 2+1D QCD $\rightarrow$ 3+1D QCD $\rightarrow$ QCD with additional matter content.

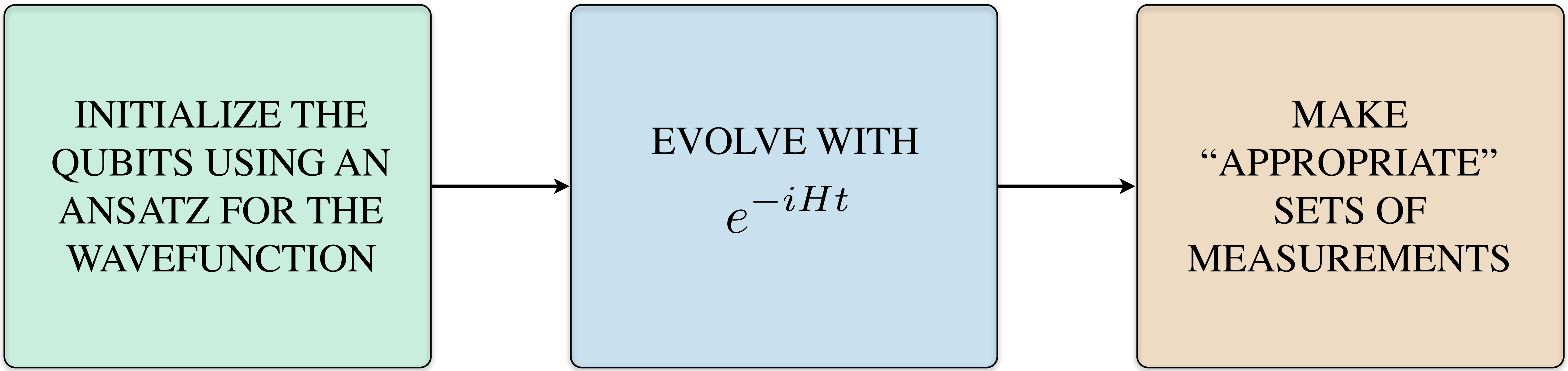
The tensor renormalization group is poised for success

Judah F. Unmuth-Yockey

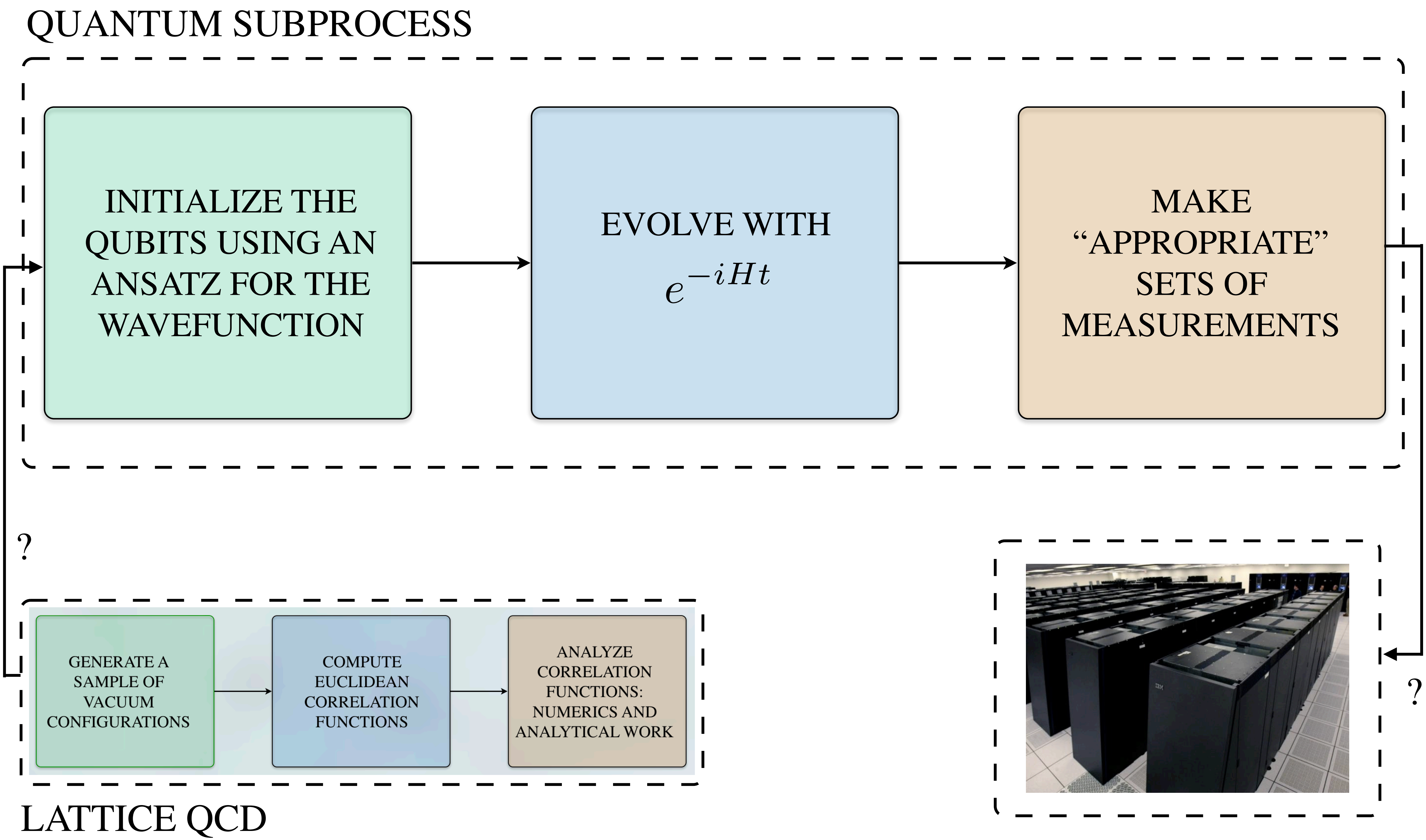
Syracuse University, Syracuse NY, U.S.A.

further investigation of these higher-dimensional algorithms. If the loss in accuracy due to these truncations is negligible, or can be overcome through algorithmic tricks, the payoff when studying relevant physical models could be large. Moreover, if we apply ourselves to

Approaches to avoid sign problem based on quantum computing



Approaches to avoid sign problem based on quantum computing



Approaches to avoid sign problem based on quantum computing

Designing Quantum Algorithms for State Preparation and Thermal Field Theory

Ning Bao[a], Andreas Hackl[b], Masazumi Honda[c], Taku Izubuchi[de*], Chulwoo Jung[d], Yuta Kikuchi[de], Daniel Knüttel[b], Christoph Lehner[bd], Peter J. Love[fa], Robert D. Pisarski[d], Gumaro Rendón[d], Akio Tomiya[e], Raju Venugopalan[d]

We also wish to have a fruitful relationship with quantum computer device design so that we could rapidly become aware about the near-future availability of specific quantum computing resources, and will be able to provide input about design and potential device application from a theoretical perspective, the Co-design concepts of the emerging center C^2QA. Exploiting specific patterns of connectivity of qubits

The need for fast and easy access to facilities for quantum computation/simulations

Yannick Meurice, Judah Unmuth-Yockey, Simon Catterall, David Berenstein, Michael McGuigan, Seth Lloyd, Richard Brower, Alexei Bazavov, Muhammad Asaduzzaman, and Stephen Jordan for the QuLAT collaboration

the DOE. One could envisage a collaboration of US HEP-QIS theorists who's main goal would be to evaluate individual proposals and coordinate access to different hardware platforms available at national labs or commercial sites. It

Approaches to avoid sign problem based on quantum computing

Benchmarking Quantum Platforms with High Energy Physics

Erik J. Gustafson,[1,*] Henry Lamm,[2,†] and Yannick Meurice[1,‡]

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Practical Quantum Advantages in High Energy Physics

Marcela Carena,[1,2,3,*] Henry Lamm,[1,†] Scott Lawrence,[4,‡] Ying-Ying Li,[1,§] Joseph D. Lykken,[1,¶] Lian-Tao Wang,[2,**] and Yukari Yamauchi[5,††]

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Exploring Digitizations of Quantum Fields for Quantum Devices

Erik Gustafson,[1] Hiroki Kawai,[2,*] Henry Lamm,[3,†] Indrakshi Raychowdhury,[4,‡] Hersh Singh,[5,6,§] Jesse Stryker,[4,6,¶] and Judah Unmuth-Yockey[7]

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Field theories on a quantum computer

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Quantum Simulation of Quantum Field Theories for High Energy Physics

Zohreh Davoudi[1], Stephen Jordan[2], Yannick Meurice[3], Christopher Monroe[4], James Osborn[5], John Preskill[6], and Irfan Siddiqi[7]

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Snowmass LOI: Front-form calculations on near-term and far-future quantum computers.

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Tensor Network methods for lattice field theories

Nouman Butt[1], Xiao-Yong Jin[1], James C. Osborn*[1], and Zain Saleem[1]

[1] Argonne National Laboratory

Simulations for HEP with SQMS Quantum Hardware

Authors: Sohaib Alam (Rigetti), Anna Grasielino (Fermilab), Roni Harnik[1] (Fermilab), Henry Lamm (Fermilab), Gabriel Perdue (Fermilab), Matt Reagor (Rigetti), Eleanor Rieffel (NASA Ames), Alex Romanenko (Fermilab), Panagiotis Spentzouris (Fermilab), Norm Tubman (NASA Ames), Davide Venturelli (NASA Ames)

Neutral Atom Quantum Simulators for HEP

Markus Greiner[1], Mikhail Lukin[1], Vladan Vuletic[2], and Martin Zwierlein[2]

[1] Department of Physics, Harvard University, Cambridge, MA, USA
[2] Department of Physics, Massachusetts Institute of Technology, Cambridge, MA, USA

Trapped-ion Quantum Simulators for High-Energy Physics

Zohreh Davoudi[1,2], Norbert Linke[1,3], Christopher Monroe[1,3], and Guido Pagano[4]

[1] Department of Physics, University of Maryland, College Park, MD 20742, USA
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[4] Department of Physics and Astronomy, Rice University, Houston, TX 77005

Session's agenda

13:00

Introduction to the session
Zoom 11

Hadron structure and spectroscopy
Zoom 11

Light and heavy flavor physics brie
Zoom 11

Fundamental Symmetries brief
Zoom 11

v-Nucleus scattering brief
Zoom 11

BSM with LGT brief
Zoom 11

Computation and algorithm brief
Zoom 11

Hamiltonian simulation and sign pr
Zoom 11

Panel discussion *Andreas Kronfeld et al.*

14:00

Zoom 11 13:45 - 14:30

Panel discussion

Oct 6, 2020, 1:45 PM
45m
Zoom 11

124. Lattice Gauge Theor...

Speakers

- Andreas Kronfeld (Fermilab)
- Anna Hasenfratz (university of colorad...)
- Carleton DeTar (University of Utah)
- Chulwoo Jung (Brookhaven National...)
- Norman Christ (Columbia University)
- Rajan Gupta (Los Alamos National...)
- Ruth Van de Water (Fermilab)
- Sasa Prelovsek (University of Ljubljana)
- Taku Izubuchi (Brookhaven National...)

Description

Discussions will be organized around the following questions:

1) What areas of the LGT program in general, and the topic you are representing in particular, require a comprehensive study to be conducted as part of the Snowmass process in order to quantify the impact of the LGT results on improving phenomenological constraints and the overall experimental programs. i.e., are there areas for which we need to go beyond the USQCD whitepapers and do a more thorough study?

2) What are the computational, algorithmic, and human resource requirements of the program to achieve the impact identified and quantified in the previous question? What is the best HPC model that facilitates scientific progress in our community? If we were to have an input in the development of the upcoming machines and technologies, what would we propose? What is the significance of new classical algorithms, and how can they be combined with developing paradigms based on Machine Learning and Quantum Computing to expedite our scientific output already in the next decade?